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(54) **PRESENTATION OF VIRTUAL ARRAYS USING N-PORT ID VIRTUALIZATION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 304 days.

This patent is subject to a terminal disclaimer.

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(52) **U.S. Cl.**
CPC ***G06F 3/0637*** (2013.01); ***G06F 3/0605*** (2013.01); ***G06F 3/0689*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,247,632 A	9/1993	Newman	
5,568,629 A	10/1996	Gentry et al.	
5,963,555 A	10/1999	Takase et al.	
6,336,152 B1	1/2002	Richman et al.	
6,421,711 B1 *	7/2002	Blumenau et al.	709/213
6,563,834 B1	5/2003	Ogawa	
6,684,209 B1	1/2004	Ito et al.	
6,839,750 B1	1/2005	Bauer et al.	
6,907,505 B2	6/2005	Cochran et al.	
6,944,785 B2	9/2005	Gadir et al.	
7,043,663 B1	5/2006	Pittelkow et al.	
7,051,101 B1	5/2006	Dubrovsky et al.	
7,120,728 B2	10/2006	Krakirian et al.	
7,124,143 B2	10/2006	Matsunami et al.	
7,260,737 B1	8/2007	Lent et al.	
7,318,120 B2	1/2008	Rust et al.	
7,340,639 B1	3/2008	Lee et al.	

(Continued)

FOREIGN PATENT DOCUMENTS

EP	1130514 A2	9/2001
EP	1357465 A	10/2003
WO	03/062979 A	7/2003

OTHER PUBLICATIONS

Office Action for U.S. Appl. No. 11/318,734 mailed Sep. 22, 2008 (44 pages).

(Continued)

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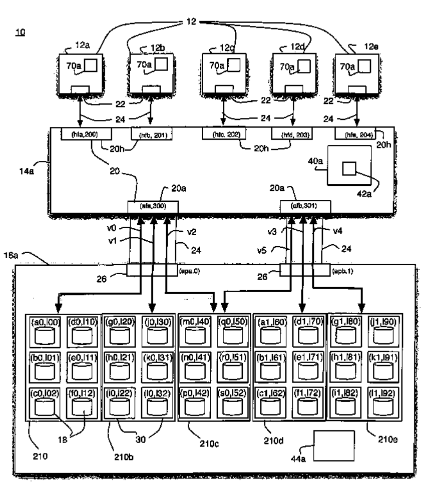
(57) **ABSTRACT**

A storage array presents virtual arrays to hosts through use of virtual port IDs. The storage array includes groups of logical units of storage. The groups are coupled to a switch through at least one physical port. Each group is assigned a unique virtual port ID for each physical port to which it is coupled. The virtual port IDs are assignable by the switch. The virtual port IDs are used by hosts coupled to the switch to exchange data with the groups to which the virtual port IDs are assigned. Further, a zoning table in the switch can associate each virtual port ID to a host facing port on the switch. In this case each host can communicate only with groups of logical units that are assigned virtual IDs associated with the host facing port to which it is coupled.

23 Claims, 12 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

7,366,846	B2	4/2008	Boyd et al.	
7,383,357	B2	6/2008	Leichter et al.	
7,398,421	B1	7/2008	Limaye et al.	
7,433,948	B2	10/2008	Edsall et al.	
7,500,134	B2	3/2009	Madnani et al.	
7,979,517	B1 *	7/2011	Wang et al.	709/221
2002/0071386	A1	6/2002	Gronke	
2002/0165982	A1	11/2002	Leichter et al.	
2003/0018927	A1	1/2003	Gadir et al.	
2003/0131182	A1	7/2003	Kumar et al.	
2004/0054866	A1	3/2004	Blumenau et al.	
2004/0133576	A1	7/2004	Ito et al.	
2004/0139240	A1	7/2004	DiCorpo et al.	
2004/0151188	A1	8/2004	Maveli et al.	
2004/0177228	A1	9/2004	Leonhardt et al.	
2004/0213272	A1	10/2004	Nishi et al.	
2004/0243710	A1	12/2004	Mao	
2005/0008016	A1	1/2005	Shimozono et al.	
2005/0010688	A1	1/2005	Murakami et al.	
2005/0015415	A1	1/2005	Garimella et al.	
2005/0120160	A1	6/2005	Plouffe et al.	
2005/0154849	A1	7/2005	Watanabe	
2005/0204104	A1	9/2005	Aoshima et al.	
2005/0243611	A1	11/2005	Lubbers et al.	
2005/0251620	A1	11/2005	Matsunami et al.	
2006/0041595	A1	2/2006	Taguchi et al.	
2006/0047930	A1	3/2006	Takahashi et al.	
2006/0064466	A1	3/2006	Shiga et al.	
2006/0075005	A1	4/2006	Kano et al.	
2006/0080516	A1	4/2006	Paveza et al.	
2006/0107010	A1	5/2006	Hirezaki et al.	
2006/0155777	A1	7/2006	Shih et al.	
2006/0190698	A1	8/2006	Mizuno et al.	
2007/0220310	A1	9/2007	Sharma et al.	
2007/0234342	A1	10/2007	Flynn et al.	
2007/0266212	A1	11/2007	Uchikado et al.	
2007/0291785	A1	12/2007	Sharma et al.	
2008/0005468	A1	1/2008	Faibish et al.	
2008/0086608	A1	4/2008	Kano	
2010/0185828	A1 *	7/2010	Kano	G06F 3/0605 711/165

OTHER PUBLICATIONS

Office Action for U.S. Appl. No. 11/318,719 mailed Sep. 17, 2008 (21 pages).

Office Action mailed Sep. 3, 2008 for U.S. Appl. No. 11/427,646.

Office Action mailed Dec. 9, 2008 for U.S. Appl. No. 11/427,724.

Final Office Action mailed Sep. 17, 2008 for U.S. Appl. No. 11/427,749.

Office Action mailed Jul. 20, 2009 for U.S. Appl. No. 11/427,724.

Office Action mailed Oct. 2, 2009 for U.S. Appl. No. 11/771,604.

Final Office Action mailed Oct. 21, 2009 for U.S. Appl. No. 11/318,734.

Final Office Action mailed Oct. 28, 2009 for U.S. Appl. No. 11/318,719.

Notice of Allowance mailed Dec. 3, 2009 for U.S. Appl. No. 11/318,719.

Notice of Allowance mailed Dec. 11, 2009 for U.S. Appl. No. 11/318,734.

Notice of Allowance mailed Nov. 16, 2009 for U.S. Appl. No. 11/427,646.

Final Office Action mailed Dec. 2, 2009 for U.S. Appl. No. 11/427,759.

Final Office Action mailed Dec. 14, 2009 for U.S. Appl. No. 11/427,744.

Final Office Action mailed Dec. 14, 2009 for U.S. Appl. No. 11/427,749.

Final Office Action mailed Dec. 29, 2009 for U.S. Appl. No. 11/427,731.

Office Action mailed Nov. 27, 2009 for U.S. Appl. No. 11/771,686.

Notice of Allowance mailed Mar. 6, 2010 for U.S. Appl. No. 11/427,724.

Office Action mailed Nov. 16, 2010 for U.S. Appl. No. 11/427,731.

Office Action mailed Dec. 16, 2010 for U.S. Appl. No. 11/427,749.

Office Action mailed Dec. 13, 2010 for U.S. Appl. No. 11/427,744.

Office Action mailed Feb. 3, 2011 for U.S. Appl. No. 11/427,759.

Final Office Action mailed Jul. 2, 2010 for U.S. Appl. No. 11/771,604.

Final Office Action mailed Jun. 23, 2010 for U.S. Appl. No. 11/771,686.

Office Action mailed May 6, 2011 for U.S. Appl. No. 11/427,731, 23 pgs.

Office Action mailed Apr. 21, 2011 for U.S. Appl. No. 11/771,686, 23 pgs.

Non-Final Office Action in related U.S. Appl. No. 11/771,604, mailed on Aug. 15, 2012; 17 pages.

Final Office Action in related U.S. Appl. No. 11/771,604, mailed on Apr. 5, 2012; 21 pages.

Final Office Action in related U.S. Appl. No. 11/427,759, mailed on Jul. 21, 2011; 15 pages.

Final Office Action in related U.S. Appl. No. 11/427,744, mailed on Sep. 16, 2011; 21 pages.

Final Office Action in related U.S. Appl. No. 11/427,749, mailed on Sep. 21, 2011; 17 pages.

Notice of Allowance in Related U.S. Appl. No. 11/771,686, mailed on Mar. 9, 2015; 9 pages.

Notice of Allowance in related U.S. Appl. No. 11/427,731, mailed on Apr. 12, 2013; 10 pages.

Notice of Allowance in related U.S. Appl. No. 11/427,744, mailed on Apr. 12, 2013; 12 pages.

Notice of Allowance in related U.S. Appl. No. 11/427,759, mailed on Jul. 5, 2013; 20 pages.

Notice of Allowance in related U.S. Appl. No. 11/427,749, mailed on Dec. 18, 2012; 5 pages.

International Search Report for PCT/US2006/062353 on Aug. 20, 2007, 3 pages.

Ofer; U.S. Appl. No. 11/318,719, filed Dec. 27, 2005; 73 pages.

Madnani; U.S. Appl. No. 11/318,675, filed Dec. 27, 2005; 90 pages.

Ofer; U.S. Appl. No. 11/318,734, filed Dec. 27, 2005; 75 pages.

Brown, et al.; U.S. Appl. No. 11/427,646, filed Jun. 29, 2006; 47 pages.

Ofer, et al.; U.S. Appl. No. 11/427,759, filed Jun. 29, 2006; 76 pages.

Ofer, et al.; U.S. Appl. No. 11/427,724, filed Jun. 29, 2006; 78 pages.

Madnani, et al.; U.S. Appl. No. 11/427,731, filed Jun. 29, 2006; 82 pages.

Madnani, et al.; U.S. Appl. No. 11/427,744, filed Jun. 29, 2006; 83 pages.

Ofer, et al.; U.S. Appl. No. 11/427,749, filed Jun. 29, 2006; 76 pages.

Charles Millilgan et al., Online Storage Virtualization: The key to managing the data explosion, Proceedings of the 35th Hawaii International Conference on System Sciences, 2002, IEEE.

Office Action mailed Mar. 19, 2008 for U.S. Appl. No. 11/427,759.

Office Action mailed Mar. 20, 2008 for U.S. Appl. No. 11/427,731.

Office Action mailed Mar. 20, 2008 for U.S. Appl. No. 11/427,744.

Office Action mailed Mar. 18, 2008 for U.S. Appl. No. 11/427,749.

Notice of Allowance mailed Jun. 12, 2008 for U.S. Appl. No. 11/318,675.

Office Action mailed Nov. 26, 2012 for U.S. Appl. No. 11/427,731, 9 pgs.

Office Action mailed Nov. 26, 2012 for U.S. Appl. No. 11/427,744, 9 pgs.

Office Action mailed Mar. 5, 2009 for U.S. Appl. No. 11/427,646.

Office Action mailed Mar. 17, 2009 for U.S. Appl. No. 11/427,759.

Office Action mailed Apr. 27, 2009 for U.S. Appl. No. 11/427,731.

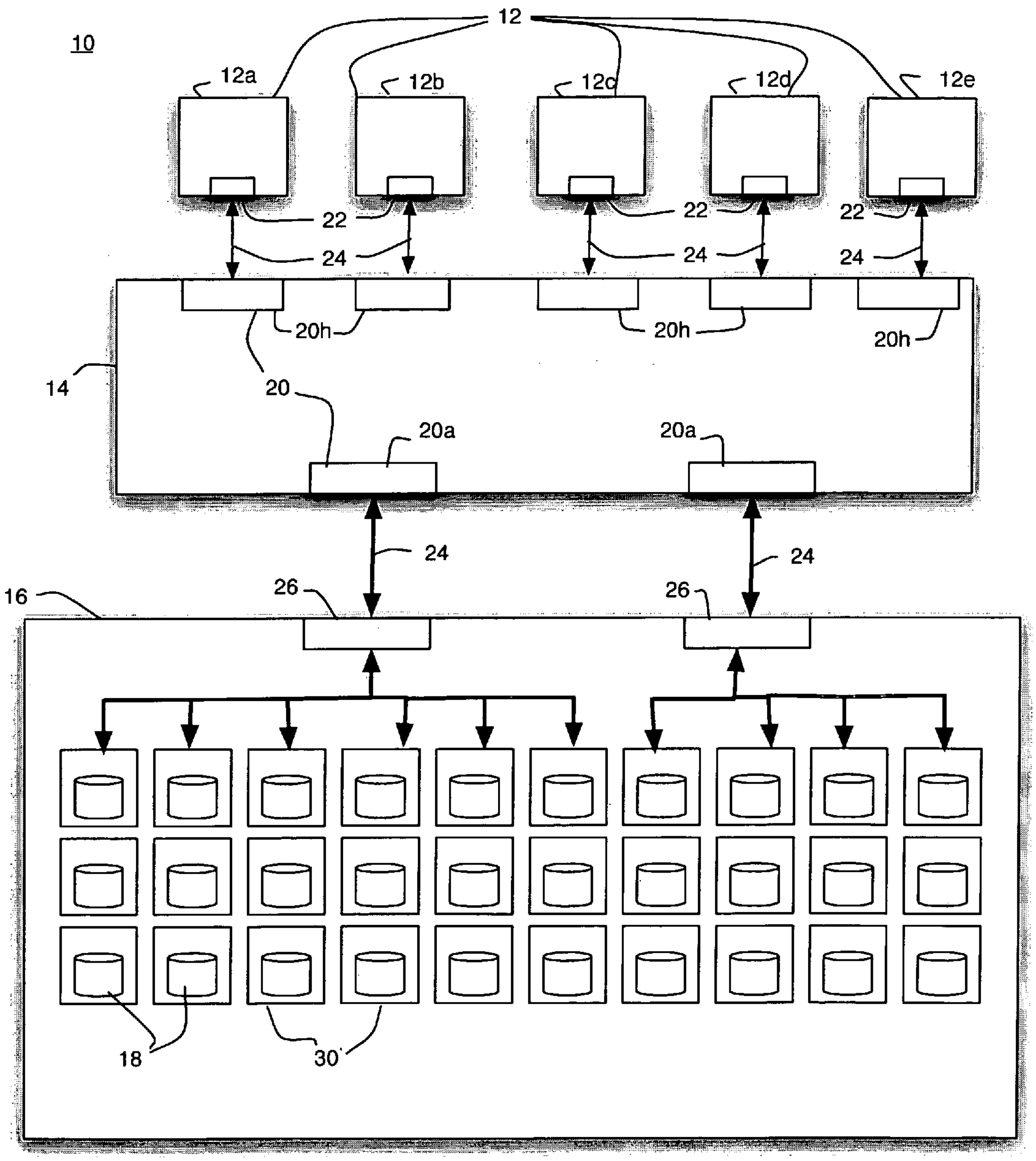
Office Action mailed Apr. 27, 2009 for U.S. Appl. No. 11/427,744.

Office Action mailed Apr. 27, 2009 for U.S. Appl. No. 11/427,749.

Office Action mailed May 7, 2009 for U.S. Appl. No. 11/318,734.

Office Action mailed May 11, 2009 for U.S. Appl. No. 11/318,719.

* cited by examiner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22
22
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20a
24
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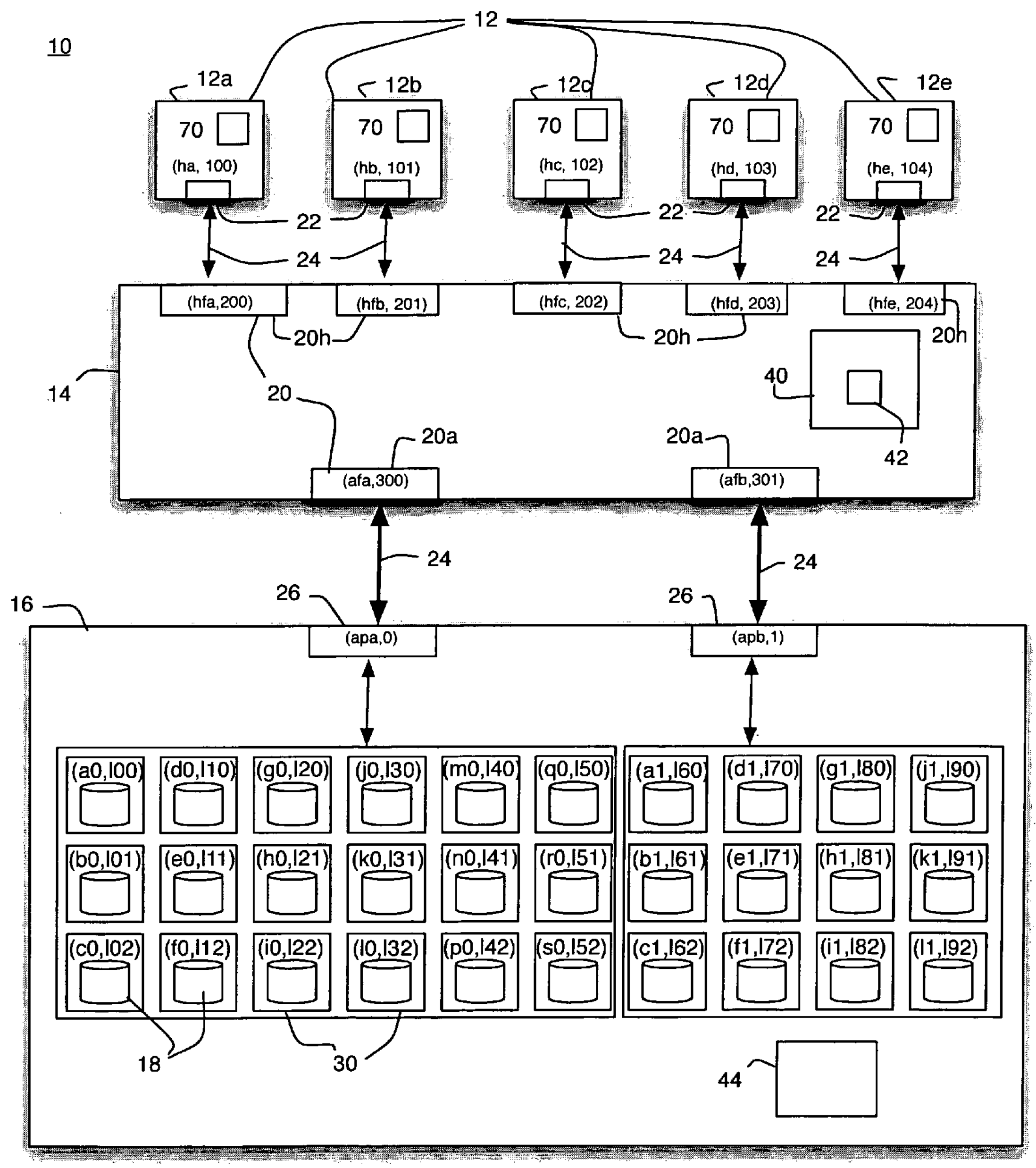
16
26
26
18
30

Fig. 1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(hfa,200)
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(hfc, 202)
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(hfe, 204)
20h
14
20
20a
40
42
(afa,300)
(afb,301)
26
16
(apa,0)
(apb,1)
(a0,l00) (d0,l10) (g0,l20) (j0,l30) (m0,l40) (q0,l50) (a1,l60) (d1,l70) (g1,l80) (j1,l90)
(b0,l01) (e0,l11) (h0,l21) (k0,l31) (n0,l41) (r0,l51) (b1,l61) (e1,l71) (h1,l81) (k1,l91)
(c0,l02) (f0,l12) (i0,l22) (l0,l32) (p0,l42) (s0,l52) (c1,l62) (f1,l72) (i1,l82) (l1,l92)
18
30
44

Fig. 2

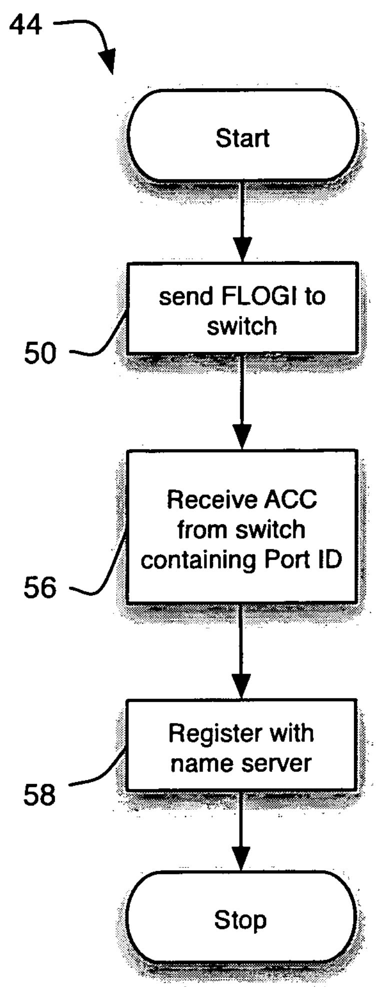
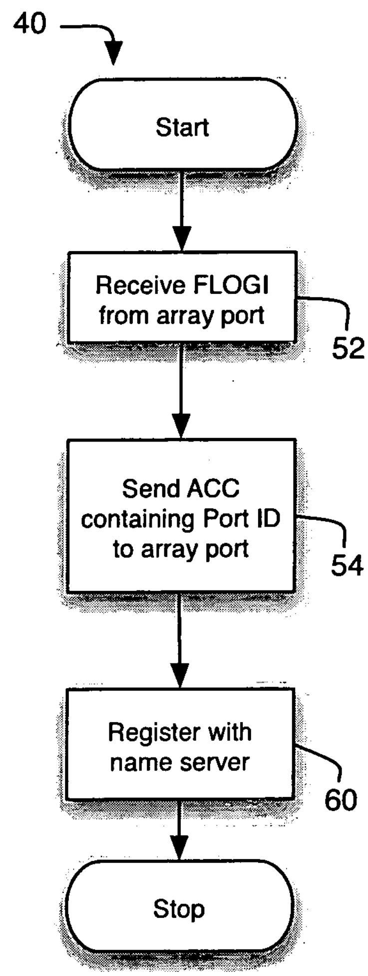

44
Start
send FLOGI to switch
50
Receive ACC from switch containing Port ID
56
Register with name server
58
Stop

Fig. 3A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Start
Receive FLOGI from array port
52
Send ACC containing Port ID to array port
54
Register with name server
60
Stop

Fig. 3B

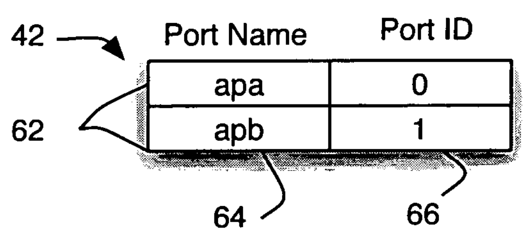


Fig. 4

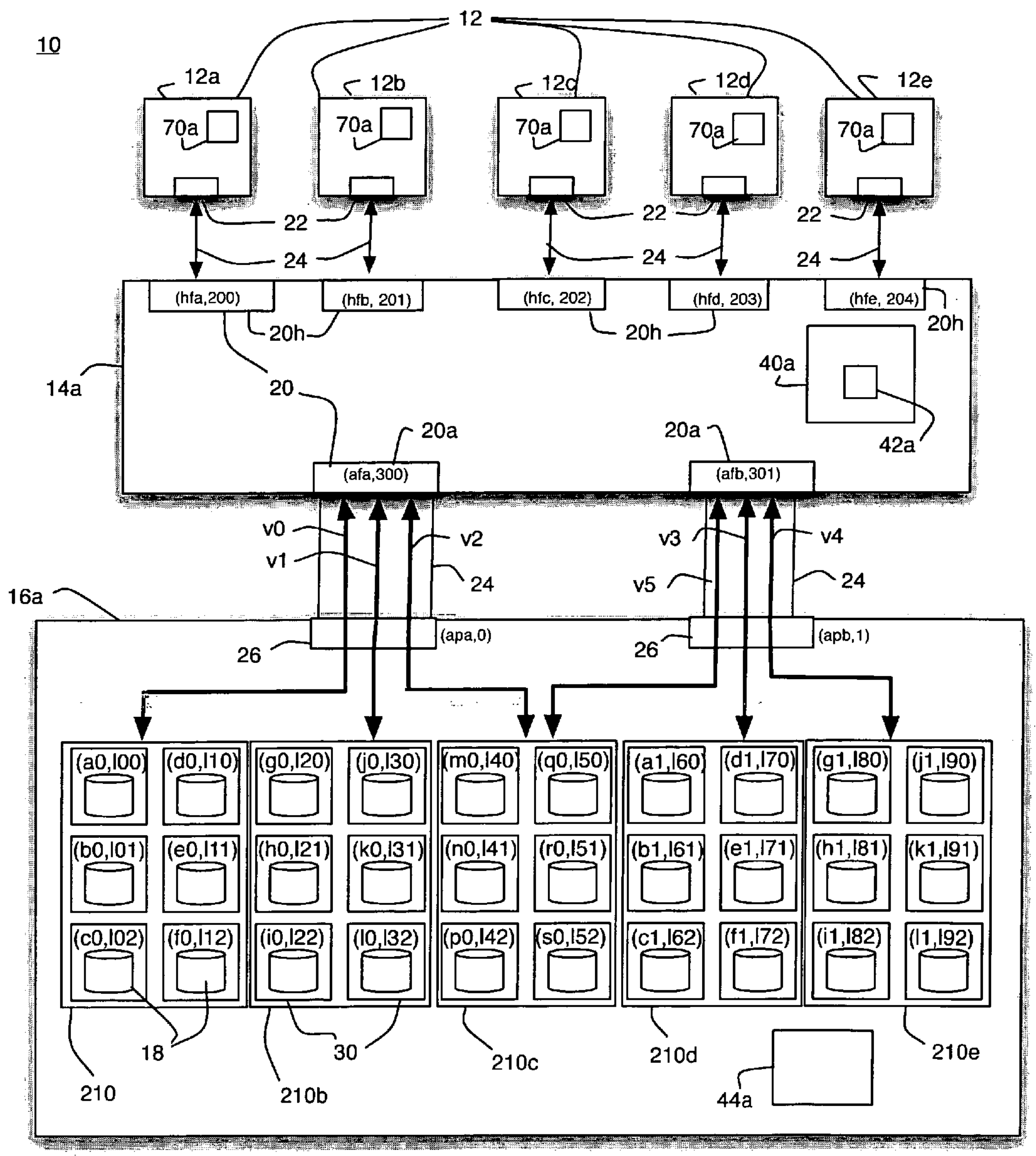
70

72

LUN Name	Port ID	LUN #
a0	0	L00
b0	0	L01
c0	0	L02
d0	0	L10
e0	0	L11
f0	0	L12
g0	0	L20
h0	0	L21
i0	0	L22
j0	0	L30
k0	0	L31
l0	0	L32
m0	0	L40
n0	0	L41
p0	0	L42
q0	0	L50
r0	0	L51
s0	0	L52
a1	1	L60
b1	1	L61
c1	1	L62
d1	1	L70
e1	1	L71
f1	1	L72
g1	1	L80
h1	1	L81
i1	1	L82
j1	1	L90
k1	1	L91
l1	1	L92

74 76 78

Fig. 5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12d
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(hfb, 201)
(hfc, 202)
(hfd, 203)
(hfe, 204)
20h
14a
20
40a
42a
20a
(afa,300)
(afb,301)
v0
v1
v2
v3
v4
v5
24
16a
26
(apa,0)
(apb,1)
(a0,l00)
(d0,l10)
(g0,l20)
(j0,l30)
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(k0,l31)
(n0,l41)
(r0,l51)
(b1,l61)
(e1,l71)
(h1,l81)
(k1,l91)
(c0,l02)
(f0,l12)
(i0,l22)
(l0,l32)
(p0,l42)
(s0,l52)
(c1,l62)
(f1,l72)
(i1,l82)
(l1,l92)
18
30
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210b
210c
210d
210e
44a

Fig. 6

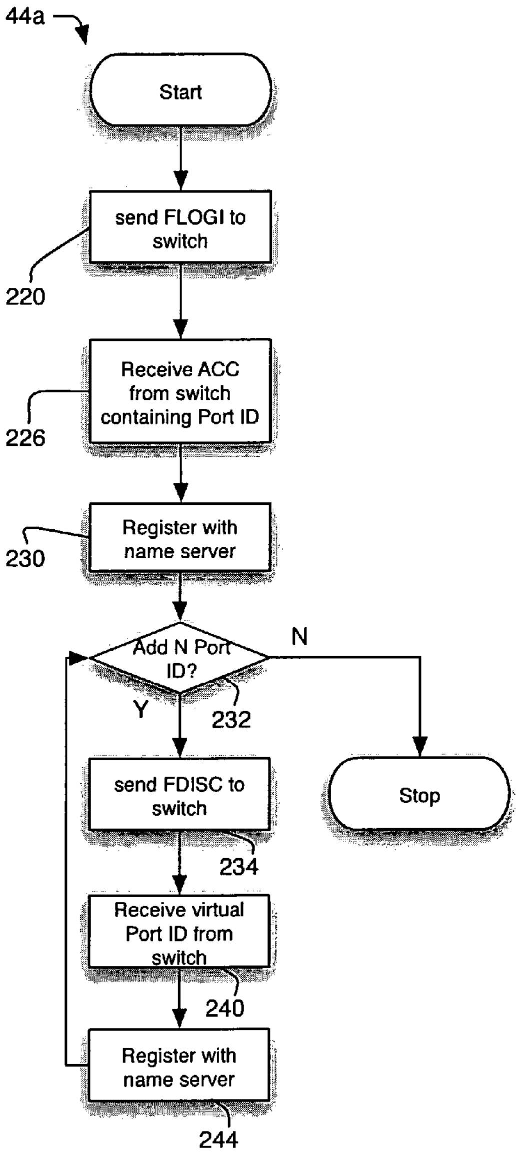

44a
Start
send FLOGI to switch
220
Receive ACC from switch containing Port ID
226
Register with name server
230
Add N Port ID?
N
Y
232
send FDISC to switch
Stop
234
Receive virtual Port ID from switch
240
Register with name server
244

Fig. 7A

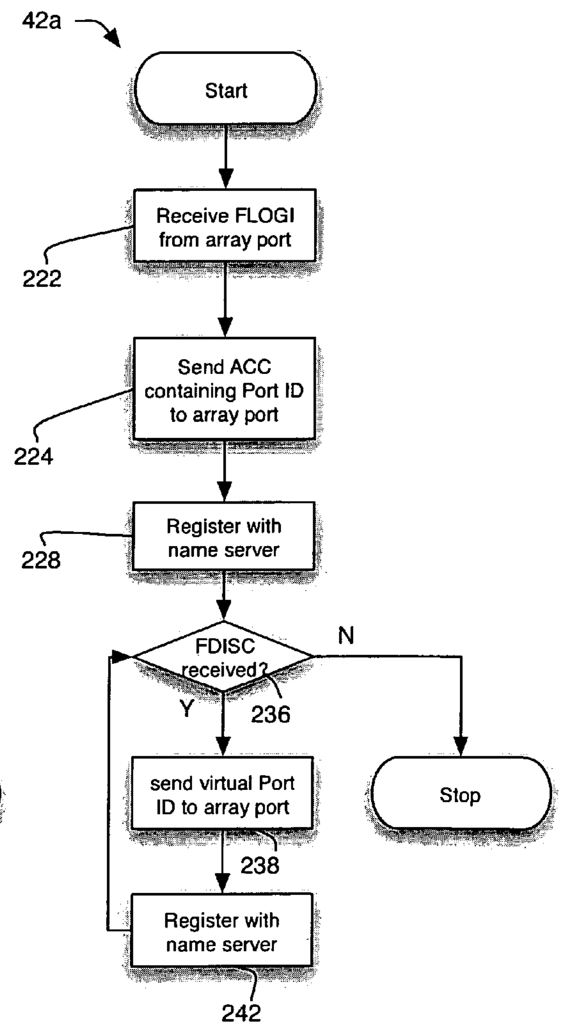

42a
Start
Receive FLOGI from array port
222
Send ACC containing Port ID to array port
224
Register with name server
228
FDISC received?
N
Y
236
send virtual Port ID to array port
Stop
238
Register with name server
242

Fig. 7B

42a

Port Name	Port ID	Virtual Port ID
apa	0	v0
apa	0	v1
apa	0	v2
apb	1	v3
apb	1	v4
apb	1	v5

62a

64a 66a 250

Fig. 8

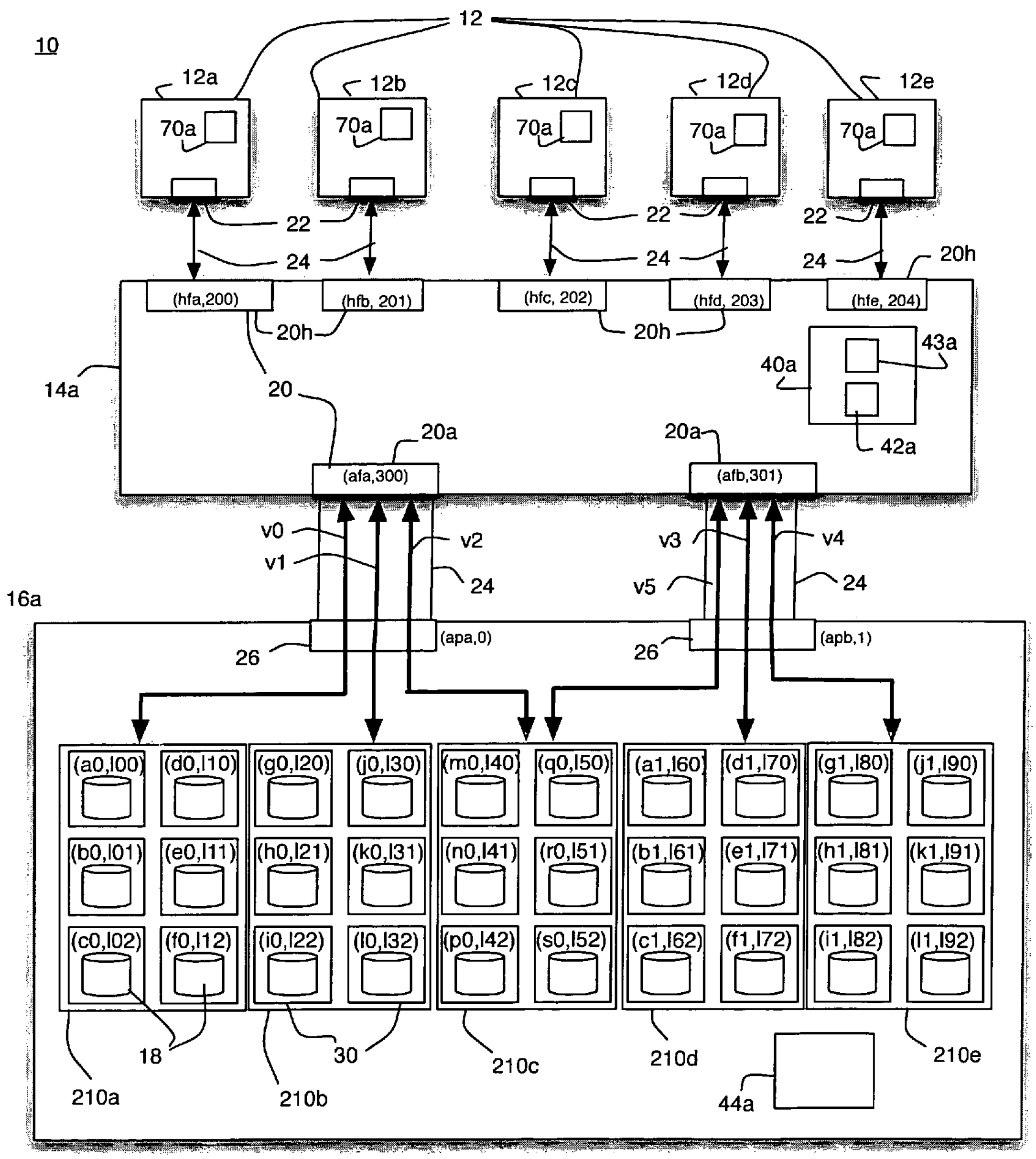
70a

72a

LUN Name	Virtual Port ID	LUN #
a0	v0	L00
b0	v0	L01
c0	v0	L02
d0	v0	L10
e0	v0	L11
f0	v0	L12
g0	v1	L20
h0	v1	L21
i0	v1	L22
j0	v1	L30
k0	v1	L31
l0	v1	L32
m0	v2	L40
n0	v2	L41
p0	v2	L42
q0	v2	L50
r0	v2	L51
s0	v2	L52
a1	v3	L60
b1	v3	L61
c1	v3	L62
d1	v3	L70
e1	v3	L71
f1	v3	L72
g1	v4	L80
h1	v4	L81
i1	v4	L82
j1	v4	L90
k1	v4	L91
l1	v4	L92
p0	v5	L42
q0	v5	L50
r0	v5	L51
s0	v5	L52

74a 76a 78a

Fig. 9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12c
12d
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(hfe, 204)
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40a
43a
42a
20a
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(afb,301)
v0
v1
v2
v3
v4
v5
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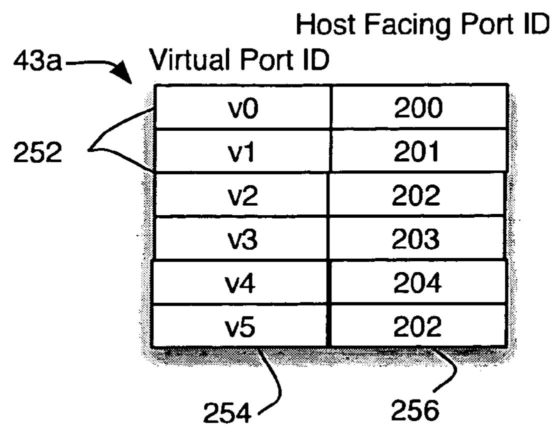
(d0,l10)
(g0,l20)
(j0,l30)
(m0,l40)
(q0,l50)
(a1,l60)
(d1,l70)
(g1,l80)
(j1,l90)
(b0,l01)
(e0,l11)
(h0,l21)
(k0,l31)
(n0,l41)
(r0,l51)
(b1,l61)
(e1,l71)
(h1,l81)
(k1,l91)
(c0,l02)
(f0,l12)
(i0,l22)
(l0,l32)
(p0,l42)
(s0,l52)
(c1,l62)
(f1,l72)
(i1,l82)
(l1,l92)
18
30
210a
210b
210c
210d
210e
44a

Fig. 10


Host Facing Port ID
43a
Virtual Port ID
252
v0
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v1
201
v2
202
v3
203
v4
204
v5
202
254
256

Fig. 11

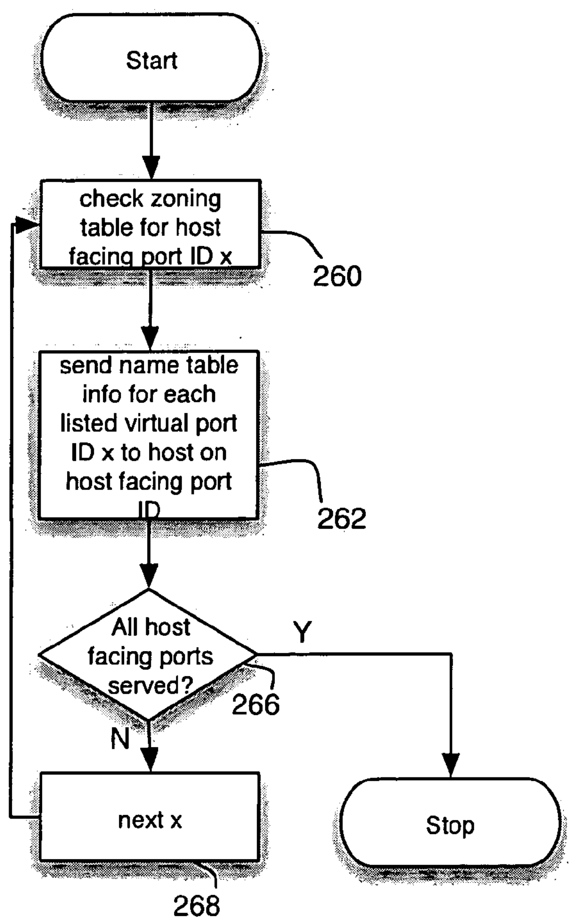
Start
check zoning table for host facing port ID x
260
send name table info for each listed virtual port ID x to host on host facing port ID
262
All host facing ports served?
Y
266
N
next x
Stop
268

Fig. 13

70a

72a

LUN Name	Virtual Port ID	LUN #
a0	v0	L00
b0	v0	L01
c0	v0	L02
d0	v0	L10
e0	v0	L11
f0	v0	L12

74a 76a 78a

Fig. 12A

70a

72a

LUN Name	Virtual Port ID	LUN #
g0	v1	L20
h0	v1	L21
i0	v1	L22
j0	v1	L30
k0	v1	L31
l0	v1	L32

74a 76a 78a

Fig. 12B

PRESENTATION OF VIRTUAL ARRAYS USING N-PORT ID VIRTUALIZATION

FIELD OF THE INVENTION

The present invention relates generally to the field of storage systems, and particularly to ways of presenting virtual arrays.

BACKGROUND OF THE INVENTION

Today's enterprise data centers store ever-larger amounts of business critical data that must be immediately and continuously available. Ever larger and more complex storage systems are used for storage of the data. Many different hosts and applications access data on these storage systems. In order to provide security and prevent data corruption, it is often necessary to ensure that the applications and hosts have exclusive access to particular areas of storage in the system.

One mechanism for partitioning storage systems employs the concept of "virtual arrays". Accordingly, software is provided within a storage array to logically partition the array into separate storage groups. These groups are accessible only to hosts that have been granted access by the storage array. Other hosts cannot access a storage group to which they have not been granted access. Unfortunately, the current methods for partitioning storage arrays into virtual arrays are highly complex and expensive, and operate only at the storage array level. It is desirable to provide a simpler, inexpensive means of presenting virtual arrays to host systems, and to provide a way of centralizing array partitioning from another part of the system—for example, the fabric.

SUMMARY OF THE INVENTION

In accordance with the principles of the invention, a storage array includes a plurality of groups of logical units of storage. At least one physical port is coupled to the groups. The groups are coupled to a switch through the at least one physical port. Each group is assigned a unique virtual port ID for each physical port to which it is coupled. Further in accordance with the invention, the virtual port IDs are assignable by the switch. The virtual port IDs are is used by hosts coupled to the switch to exchange data with the groups to which the virtual port IDs are assigned.

The invention is particularly applicable in a Fibre Channel fabric environment. Each group of logical units thereby has its own unique virtual port ID through which it can be addressed by a host. The groups thus appear to the host as separate virtual arrays In accordance with a further aspect of the invention, the switch includes host facing ports. Each host is coupled to the switch through a host facing port. A zoning table in the switch associates each virtual port ID to a host facing port. Each group communicates only with hosts coupled to host facing ports associated with the virtual ID assigned to the group. Each group now appears to a host as a separate physical storage array.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to facilitate a fuller understanding of the present invention, reference is now made to the appended drawings. These drawings should not be construed as limiting the present invention, but are intended to be exemplary only.

FIG. **1** is a representation of a storage area network. The storage area network includes a Fibre Channel array and hosts coupled to a Fibre Channel fabric switch.

FIG. **2** is a representation of the storage area network of FIG. **1**, showing Fibre Channel port IDs and LUN names and numbers.

FIG. **3**A is a flow diagram representing the operation of the array controller during Fibre Channel system initialization.

FIG. **3**B is a flow diagram representing the operation of the switch during Fibre Channel system initialization.

FIG. **4** is a representation of a name table managed by the name server database in the switch.

FIG. **5** is a representation of a LUN table in a host.

FIG. **6** is a representation of a storage area network wherein the LUNs in the storage array are arranged into groups and are separately addressable via virtual port IDs in accordance with the invention.

FIG. **7**A is a flow diagram representing the operation of the array controller during Fibre Channel system initialization when virtual port IDs are implemented on the storage array.

FIG. **7**B is a flow diagram representing the operation of the switch during Fibre Channel system initialization when virtual port IDs are implemented on the storage array.

FIG. **8** is a representation of the name table in the switch in accordance with the invention.

FIG. **9** is a representation of a LUN table in a host in accordance with the invention.

FIG. **10** is a representation of the system of FIG. **6** wherein the name server database in the switch further includes a zoning table.

FIG. **11** is a representation of the zoning table of FIG. **10**.

FIG. **12**A is a representation of a LUN table in one host when the zoning table in the switch is operational.

FIG. **12**B is a representation of a LUN table in a second host when the zoning table in the switch is operational.

FIG. **13** is a flow diagram representing the operation of the switch when a zoning table is in use.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

In FIG. **1** there is shown a functional block diagram of an exemplary storage area network **10** in which the invention can be implemented. The storage area network **10** employs a Fibre Channel fabric topology. Fibre Channel is a high speed serial transport used in storage systems. It is described in a series of standards that can be found at X3T9.3 Task Group of ANSI: *Fibre Channel Physical and Signaling Interface* (FC-PH), Rev. 4.2 Oct. 8, 1993. Hosts **12**, shown individually as **12***a*, **12***b*, **12***c*, **12***d* and **12***e* are coupled to a Fibre Channel "fabric" in the storage system, herein shown as a switch **14**. A storage array **16** including disk drives **18** is also coupled to the switch **14**. The hosts **12** communicate with the disk drives **18** via a cross-point Fibre Channel connection through the switch **14**.

The switch **14** includes switch ports **20**. Host facing switch ports are labeled as **20***h*. Array facing switch ports are labeled as **20***a*. Host ports **22** on the hosts are coupled via Fibre Channel links **24** to host-facing switch ports **20***h* on the switch **14**. Physical array ports **26** on the array **16** are coupled via Fibre Channel links **24** to array-facing switch ports **20***a* on the switch **14**. The disks **18** within the array **16** are organized into logical units ("LUNs") **30**. "LUN", originally a SCSI (small computer system interface) term, is now commonly used to describe a logical unit of physical storage space. The LUNs are exported by the array ports **26** for access by the hosts **12** via the fibre channel links **24** and switch **14**. As herein shown, each disk appears to be configured as a separate LUN, though it is understood that a LUN can encompass part of a disk, or parts of multiple disks, or multiple complete disks. The arrangement shown is chosen for convenience of description.

In a Fibre Channel system such as that of FIG. **1**, each Fibre Channel device (including but not limited to host ports and array ports) has two identifying characteristics—a name and an address. Fibre Channel names, known as "world wide names", are unique—every Fibre Channel device in the world has its own unique name. Each Fibre Channel device in a system also has an address, referred to in Fibre Channel parlance as an "ID", that is dynamic and dependent upon the configuration of the system. The IDs are used for directing information between hosts and arrays in the system. Port addresses are commonly referred to as "port IDs". LUN addresses are commonly referred to as "LUN numbers". After initialization, the hosts **12** communicate with the array ports **26** and LUNs **30** by sending messages to the appropriate port ID and LUN number.

In a Fabric topology, the switch **14** assigns IDs to the host ports **22** and array ports **26** during initialization. IDs as described in the Fibre Channel specification are actually 24 bit quantities containing several fields. In FIG. **2** names and IDs are shown symbolically with alphanumeric symbols for simplicity of explanation. The names and IDs of each port and LUN are shown as a pair (name, ID). For instance, the host port **22** on the host **12***a* is shown to have a name and ID of (ha, **100**). The names and IDs for the ports **22** on the hosts **12***b-e* are (hb, **101**), (hc, **102**), (hd, **103**) and (he, **104**). The host-facing switch ports **20***h* are shown to have names and IDs (hfa, **200**), (hfb, **201**), (hfc, **202**), (hfd, **203**), and (hfe, **204**). Array-facing switch ports **20***h* are shown to have names and IDs (afa, **300**) and (afb, **301**). The array ports **26** are shown to have names and IDs (apa, **0**), and (apb, **1**). Each LUN **30** has a name and LUN number. For example, the LUN of name a**0** is LUN number L**00**. LUN numbers L**00**, L**01**, L**02**, L**10**, L**11**, L**12**, L**20**, L**21**, L**22**, L**30**, L**31**, L**32**, L**40**, L**41**, L**42**, L**50**, L**51**, AND L**52** are shown as accessible via array port ID **0**. LUN numbers L**60**, L**61**, L**62**, L**70**, L**71**, L**72**, L**80**, L**81**, L**82**, L**90**, L**91**, and L**92** are shown as accessible via array port ID **1**.

The Fibre Channel switch **14** includes a name server database **40**. The name server database **40** is used by the switch **14** to assign IDs to host ports **22** and array ports **26** during initialization. The name server database **40** includes a name server table **42** that is used by the switch to resolve IDs to names. The general process by which port IDs are assigned in accordance with the Fibre Channel T1 standard is shown in FIGS. **3**A and **3**B. FIG. **3**A shows the process by which the switch **14** assigns Port IDs. FIG. **3**B shows the process by which the fibre channel array controller **44** in the array **16** (FIG. **2**) communicates with the switch **14**. First, each array port (i.e. ports **0** and **1**) is logged in to the switch **14** by the array controller **44** (FIG. **3**A step **50**). The port logins are received by the name server database **40** (FIG. **3**B step **52**.) When the switch **14** receives a port login ("FLOGI") command, it responds by sending an acknowledgement message to the array controller **44** (FIG. **3**B step **54**). This acknowledgement message contains a Port ID for the array port that was logged in. The acknowledgement message is received by the array controller **44** (FIG. **3**A step **56**). Then, a registration process is performed by the switch **14** (FIG. **3**A step **58**, FIG. **3**B step **60**). During the registration process, the name server table **42** is built and distributed to nodes registered to receive it.

An example of the name server table **42** is shown in FIG. **4**. The full contents of the name server table **42** are described in the Fibre Channel Name Server MIB, described in the IETF RFC **4044**, "Fibre Channel Management MB", herein incorporated by reference. FIG. **3** shows only enough of the table **42** to contribute to understanding of the invention. The table **42** includes multiple entries **62**, each including a port name field **64** and a port address ID field **66**. During the registration process of FIGS. **3**A and **3**B, the entries **62** are populated with the switch port **26** names and Port IDs assigned by the switch **14**. For the example array **16** shown in FIG. **1**, an entry **44** includes the port name apa and Port ID **0**, while another entry **62** includes the port name apb and Port ID **1**. The switch **14** then sends this table **42** to all members of the SAN **10** registered to receive state change notifications. This includes the hosts **12**. The hosts **12** now have the Port IDs of the array ports **26** so Fibre Channel communications between the hosts **12** and array **16** can ensue.

Now that the hosts have IDs to access the ports, they can learn what. LUNs are available. LUN names and numbers are managed at the array level. Each host **12** sends a query to each array port **26** ID in turn, requesting a list of available LUN numbers. Once the LUN numbers for a given array port ID are known, the host is able to query each LUN **30** by using a combination of the port ID and LUN number to access the LUNs **30**. The host **12** then queries each LUN **30** for its corresponding LUN name. Once the host has gathered all this information, it builds a directory LUN table **70** that relates LUN names, port IDs, and LUN numbers. A representation of such a LUN table **70** is shown in FIG. **5**. The table includes an entry **72** for each LUN it has discovered. Each entry includes a LUN name field **74**, a port ID field **76** and a LUN number field **78**, which in combination identify the LUN **30**. The table **70** for a host **12** of FIG. **2** includes the LUN names, port IDs, and LUN numbers for the LUNs **30** on the array **16** for each port ID **0** and **1**. For example, one entry **72** shows a LUN with name a**0** and LUN number L**00** associated with Port ID **0**. Another entry **72** shows a LUN with name k**0** and address L**31** associated with Port ID **0**. Yet another entry **72** shows a LUN with name e**1** and LUN number L**71** associated with Port ID **1**.

During operation, hosts **12** refer to LUNs **30** by their LUN numbers. In order to access a LUN **30**, a host **12** port **22** sends a message whose Fibre Channel address includes the array port ID and LUN number. The switch **14** parses the port ID portion of the address in order to forward the message to the identified array port **26**. The array **16** then uses the LUN number portion of the address to access the proper LUN **30** within the array **16**. So, for example, if host **12***a* needs to access LUN #L**71**, the host **12***a* port **22** sends a message to an address including the port ID **1** and the LUN number L**71**. The switch **14** sees the port ID **1** and sends the message to the array port **26** with ID **1**. The array sees that the message is directed to LUN # L**71** and thus proceeds to perform the appropriate operation on LUN #L**71**.

Note that, in accordance with the prior art arrangement of FIG. **2**, a host has actual access to all LUNs on each array port to which it has access. For example, the host **12***a* has access to port ID **0**, and therefore has access to LUNs L**00**-L**52**.

It is often desirable to separate a storage array into several distinctly accessible sub-arrays, or "virtual arrays". Each host or application has access to a virtual array, but does not have access to the other virtual arrays within the storage array. For example, it may be desirable to arrange the LUN numbers L**00**-L**12** as a first virtual array accessible only to the host **12***a*, and LUN numbers L**20**-L**32** as a second virtual array accessible only to the host **12***b*. Such an arrangement can provide security against data corruption and can provide ease of management for host applications. But, in the prior art example of FIG. **2**, all the LUNs L**00**-L**52** are exposed via the same port ID **0**, and thus cannot be hidden at the fabric level from either host **12***a* or host **12***b*. Virtual arrays have therefore previously been provided only through implementation of complex software on the storage array.

In accordance with the principles of the invention, the storage array and fabric are employed to present virtual arrays to the hosts. The LUNs in a storage array **16** are arranged into several storage groups. The term "storage group" can have different meanings in different contexts, so for clarity, a "storage group" as used herein is simply a group of LUNs. Virtual Port IDs are established over each physical port on the array. Each storage group has assigned to it at least one virtual port ID, used by the hosts to access the storage groups. Each storage group is thus separately accessible via at least one unique virtual port ID. A host **12** can access only the LUNs **30** in a storage group with a virtual port ID to which the switch **14** allows it access. As will be seen, the provision of unique virtual IDs for each storage group allows zoning to be applied by the switch **14** such that each host **12** has access to only designated storage groups. The storage groups thus appear as individual virtual arrays to the hosts **12**. Therefore, the storage groups will herein further be referred to as "presented virtual arrays".

In FIG. **6**, the storage system **10** has been modified so that presented virtual arrays can be accessed by the hosts. The modified storage array **16***a* is shown to include presented virtual arrays **210***a*, **210***b*, **210***c*, **210***d*, and **210***e*. The LUN **30** storage groups forming the presented virtual arrays can be arranged for example by a modified fibre channel controller **44***a* (shown) or by a separate controller, or by pre-configured software programming or dynamic user programming of the array **16**, or any combination thereof. Each presented virtual array **210***a*-**210***e* is associated with at least one "virtual port ID" v**0**-v**5**. Generally, each presented virtual array **210***a*-**210***e* is assigned one or more virtual port IDs depending upon how many physical ports the virtual array is accessible through. As shown by example, the presented virtual array **210***a* is associated with the physical array Port ID **0** and is assigned one virtual port ID v**0**. The presented virtual array **210***b* is also associated with the physical array Port ID **0** and is assigned one virtual port ID v**1**. The presented virtual array **210***c* is associated with both the physical array ports Port ID **0**, **1**, and is thus assigned two virtual port IDs v**2** and v**5**. The presented virtual arrays **210***d* and **210***e* are both associated with the physical array port ID **1** and are assigned virtual port IDs v**3** and v**4** respectively.

In accordance with one implementation of the virtual Port IDs of the invention, the virtual port IDs are assigned by the modified switch **14***a*. The ANSI T11 standard " ", which currently defines virtual ports used by hosts, is extended to support storage arrays. The process by which virtual Port IDs are provided by the switch **14***a* is shown in FIGS. **7**A and **7**B. FIG. **7**A shows the process by which the fibre channel array controller **44***a* in the array **16** communicates with the switch **14***a*. FIG. **7**B shows the process by which the switch **14***a* assigns Port IDs. First, each array port (i.e. ports **0** and **1**) is logged in to the switch **14***a* by the array controller **44***a* (FIG. **7**A step **220**). The port logins are received by the switch **14***a* (FIG. **7**B step **222**.) When the switch **14***a* receives a port login ("FLOGI") command, it responds by sending an acknowledgement message to the array controller **44***a* (FIG. **7**B step **224**). This acknowledgement message contains a Port ID for the array port that logged in. The acknowledgement message is received by the array **16** controller **44***a* (FIG. **7**A step **226**). Then, a registration process is performed by the switch **14***a* (FIG. **7**A step **228**, FIG. **7**B step **230**). During the registration process, the name server table **42***a* is built as previously described with regard to name server table **42**.

Then, if virtual port IDs are needed by the array **16***a* ports **26** (step **232**), the array controller **44***a* sends an "FDISC" command to the switch **14***a* (step **234**). The switch **14***a* receives the FDISC command (step **236**) and responds by sending a virtual port ID to the array controller **44***a* (step **238**). The array controller **44***a* receives the virtual port ID from the switch **14***a* (step **240**). The switch **14***a* and array controller **44***a* then perform the registration process to add the virtual Port ID to the name server table **42***a*, as will be described (steps **242**, **244**). The FDISC command and response is repeated for each virtual ID required for each physical port (steps **232**-**244**).

Now the switch **14***a* can build the name server table **42***a* in a manner similar to that previously described with respect to name server table **42**, except the name server table **42***a* associates multiple virtual port IDs with the physical port names. An example of such a name server table **42***a* is shown in FIG. **8**. The physical array port **26** with name apa and Port ID **0** is also associated with the virtual port IDs v**0**, v**1**, v**2**, and v**5**. Likewise, the physical array port **26** with name apb and Port ID **1** is associated with the virtual port IDs v**3**, v**4**, and v**5**. At this point, the switch **14***a* can update the hosts **12** with the contents of the name server table **42***a* as previously described. The hosts **12** will thereby receive all the virtual port IDs v**0**-v**5**.

Now that the hosts **12** have the virtual port IDs v**0**-v**5**, they can build their directory LUN tables in a manner similar to that previously described with regard to FIG. **5**, except that now each virtual port ID will be associated with LUN names and numbers. Accordingly, each host **12** sends a query to each virtual array port ID v**0**-v**5** in turn, requesting a list of available LUN numbers. Once the LUN numbers for a given virtual array port ID are known, the host is able to query each LUN **30** by using a combination of the virtual port ID and LUN number to access the LUNs. The host **12** then queries each LUN **30** for its corresponding LUN name. Once the host has gathered all this information, it builds a directory LUN table **50***a* that relates LUN names, virtual port IDs, and LUN numbers. A representation of such a LUN table **70***a* is shown in FIG. **9**. The table includes an entry **72***a* for each LUN it has discovered. Each entry includes a LUN name field **74***a*, a virtual port ID field **76***a* and a LUN number field **78***a*, which in combination identify the LUN. For example, the LUNs **30** associated with the presented virtual array **210***a*—i.e. virtual port ID v**0**—are (a**0**, L**00**), (b**0**, L**01**), (c**0**, L**02**), (d**0**, L**10**), (e**0**, L**11**), and (f**0**, L**12**). Note also that the presented virtual array **210***c* (LUN#s L**40**-L**52**) is dual-ported; that is, it is accessible via virtual port IDs v**2** and v**5**. LUNs in dual-ported presented virtual arrays may have two separate LUN numbers as well, one for use when accessed on the first virtual port ID, and the second for use when accessed on the second virtual port ID. Dual-ported presented virtual arrays can be useful for high availability purposes.

In accordance with one advantage of the invention, storage array "zoning" can be implemented at the fabric switch in order to physically separate the presented virtual arrays for access only by certain hosts. Fibre Channel switches are able to implement zoning, whereby access between host ports and array ports is specified. But zoning can only be implemented at the port level; that is, it cannot be implemented at the LUN level. In the prior art arrangement of FIG. **2**, zoning cannot be used to separate the storage groups of LUNs **210***a*, **210***b*, **210***c* as shown FIG. **3**, because all the LUNs have the same Port ID **0**.

But in accordance with this further aspect of the invention, since each presented virtual array **210***a*-*e* is associated with its own unique virtual Port ID v**0**-v**5**, the switch **14***a* can differentiate between each presented virtual array **210***a-e* based upon its virtual Port ID. The switch **14***a* can be programmed to allow or disallow access to each virtual port address from each host facing array port address through the use of its zoning process. Host access to the presented virtual arrays **210***a-e* can thus be physically separated, enhancing security, data integrity, and ease of storage management for host applications.

Referring now to FIG. **10**, the switch name server database **40***a* is shown to include a zoning table **43***a* as well as a name table **42***a*. The full contents of a zoning table as used by a prior art fibre channel switch is described at " ". The zoning table **43***a* is modified in accordance with the invention to include virtual array port IDs. Only the portions of the zoning table **43***a* relevant to an understanding of the invention are shown here. Accordingly, the zoning table **43***a* has entries **252** including a virtual port ID field **254** and a host facing switch port ID field **256**. For each virtual port ID recognized by the switch **14**, the name server database **40***a* can associate one or more host facing switch port IDs with the virtual port ID. For example, in the table shown, virtual port ID v**0** is associated with host facing switch port ID **200**. Virtual port ID v**1** is associated with host facing switch port ID **201**. Virtual port ID v**2** is associated with host facing switch port ID **202**. Virtual port ID v**4** is associated with host facing switch port ID **204**. Virtual port ID v**5** is associated with host facing switch port ID **202**. (Host facing array port **202** is dual ported on virtual port IDs v**2** and v**5**.)

Now, when the switch **14***a* updates the hosts **12** with the contents of the name server table **42***a*, it uses the zoning table **43***a* to filter the presentation of the name server table **42***a* information to the hosts **12**. Referring to FIG. **12** there are shown several examples of the LUN tables **70***a* in the hosts **12***a* and **12***b*. When the switch **14***a* updates the hosts **12**, the switch **14***a* refers to the zoning table **43***a*—for example the table of FIG. **11**. The process by which the switch **14***a* uses the zoning table **43***a* is shown in FIG. **13**. The switch **14***a* checks the zoning table **43***a* for the first host facing port ID **200** (step **260**). The switch **14***a* sees that the host facing array port ID **200** is authorized to access only virtual array port v**0**. So, only the name table information associated with virtual port ID **0** is forwarded to the host **12***a* that is coupled to the host facing switch port ID **200** (step **262**). The host **12***a* thus receives the address information for the virtual port v**0**. The LUN table **70***a* for the host **12***a* thus looks like that shown in FIG. **12**A. The host **12***a* is limited to access to the LUNs L**00**-L**12** on virtual Port ID v**0**. The switch **14***a* then checks the zoning table **43***a* for access information for the host facing switch port ID **201** (steps **266**, **268**, **260**). The switch **14***a* sees that the host facing switch port ID **201** is authorized to access only virtual array port v**1**. So, only the name table information associated with virtual array port v**1** is forwarded to the host **12***b* that is coupled to the host facing switch port ID **201** (step **262**). The host **12***b* thus receives the address information for the virtual port v**1**. The LUN table **70***a* for the host **12***b* thus looks like that shown in FIG. **12**B. The host **12***b* is limited to access to the LUNs L**20**-L**32** on virtual Port ID v**1**. This process continues for each host facing switch port ID (steps **266**-**262**).

Now each host has access to only the LUNs **30** on the virtual array ports allowed by the zoning table **43***a* in the switch **14**, rather than to all LUNs **30** on a physical array port **26**. The invention thus allows a very simple and efficient means of presenting virtual arrays to the hosts, without requiring complex array level software.

The present invention is not to be limited in scope by the specific embodiments described herein. Various modifications of the present invention, in addition to those described herein, will be apparent to those of ordinary skill in the art from the foregoing description and accompanying drawings. For example, the disclosed controllers can be implemented in hardware, software, or both. All such modifications are intended to fall within the scope of the invention. Further, although aspects of the present invention have been described herein in the context of a particular implementation in a particular environment for a particular purpose, those of ordinary skill in the art will recognize that its usefulness is not limited thereto and that the present invention can be beneficially implemented in any number of environments for any number of purposes.

We claim:

1. A storage array comprising:

a plurality of physical ports for coupling the storage array to a switch; and

a plurality of individual logical units of physical storage space organized into a plurality of groups of logical units of storage, each group having at least two of the individual logical units such that the at least two individual logical units are part of the group distinguished from being mapped to the group, each group being coupled to one or more physical ports of the plurality of physical ports on the storage array, each group being assigned a unique virtual port ID that uniquely identifies the group for each physical port on the array to which the group is coupled, with each group of the plurality of groups of logical units of storage that is coupled to two or more physical ports of the plurality of physical ports being assigned a unique virtual port ID for each of the two or more physical ports to which that same group is coupled such that multiple unique virtual port IDs are assigned to that same group, wherein a group of the plurality of groups of logical units of storage is assigned multiple virtual port IDs and two physical ports of the two or more physical ports, and wherein a first virtual port ID of the multiple port IDs corresponds to the first physical port of the two physical ports and a second virtual port ID of the multiple port IDs corresponds to the second physical port of the two physical ports.

2. The storage array of claim **1** wherein the virtual port IDs are assignable by the switch.

3. The storage array of claim **2** wherein a virtual port ID is used by a host coupled to the switch to exchange data with the group to which the virtual port ID is assigned.

4. The storage array of claim **2** wherein the switch to which the groups can be coupled comprises:

host facing ports, each host facing port coupled to a host; and

a zoning table associating each virtual port ID to a host facing port.

5. The storage array of claim **4** wherein each group communicates only with hosts coupled to host facing ports associated with the virtual ID assigned to the group.

6. The storage array of claim **5** wherein the storage array is a fibre channel array and wherein the at least one physical port is a fibre channel port.

7. A system comprising:

a plurality of hosts; and

a storage array including a plurality of physical ports for coupling the storage array to a switch, the storage array including a plurality of individual logical units of physical storage space organized into a plurality of groups of logical units of storage, each group being coupled to one or more physical ports of the plurality of physical ports on the storage array, each group having at least two of the individual logical units such that the at least two individual logical units are part of the group distinguished from being mapped to the group, each group being assigned a unique virtual port ID that uniquely identifies the group for each physical port on the array to which the group is coupled, with each group of the plurality of groups of logical units of storage that is coupled to two or more physical ports of the plurality of physical ports being assigned a unique virtual port ID for each of the two or more physical ports to which that same group is coupled such that multiple unique virtual port IDs are assigned to that same group, each host communicating with a given group of the plurality of groups of logical units of storage via the switch using one of the one or more unique virtual port IDs assigned to the given group, wherein a group of the plurality of groups of logical units of storage is assigned multiple virtual port IDs and two physical ports of the two or more physical ports, and wherein a first virtual port ID of the multiple port IDs corresponds to the first physical port of the two physical ports and a second virtual port ID of the multiple port IDs corresponds to the second physical port of the two physical ports.

8. The system of claim **7** further comprising a switch, wherein the hosts and storage array are coupled to the switch, and the virtual port IDs are assigned by the switch.

9. The system of claim **8** wherein a virtual port ID is used by a host to exchange data with the group to which the virtual port ID is assigned.

10. The system of claim **8** wherein the switch comprises:

host facing switch ports via which the hosts are coupled to the switch;

a zoning table for associating virtual port IDs with host facing ports.

11. The system of claim **10** wherein each host communicates only with groups having assigned virtual IDs associated with the host facing switch port to which the host is coupled.

12. The system of claim **11** wherein the storage array is a fibre channel array and wherein the at least one physical port is a fibre channel port.

13. A method comprising the steps of:

providing a storage array including a plurality of physical ports;

coupling the storage array to a switch via the physical ports;

arranging logical units in the storage array into a plurality of individual logical units of physical storage space organized into a plurality of groups of logical units of storage, each group having at least two of the individual logical units such that the at least two individual logical units are part of the group distinguished from being mapped to the group, each group being coupled to one or more physical ports of the plurality of the physical ports on the array;

assigning to each group a unique virtual port ID that uniquely identifies the group for each physical port on the array to which it is coupled, with each group of the plurality of groups of logical units of storage that is coupled to two or more physical ports of the plurality of physical ports being assigned a unique virtual port ID for each of the two or more physical ports to which that same group is coupled such that multiple unique virtual port IDs are assigned to that same group, wherein a group of the plurality of groups of logical units of storage is assigned multiple virtual port IDs and two physical ports of the two or more physical ports, and wherein a first virtual port ID of the multiple port IDs corresponds to the first physical port of the two physical ports and a second virtual port ID of the multiple port IDs corresponds to the second physical port of the two physical ports.

14. The method of claim **13** wherein the step of assigning is performed by the switch.

15. The method of claim **14** further including the steps of:

coupling a host to the switch;

using by the host a virtual port ID to exchange data with the group in the storage array to which the virtual port ID is assigned.

16. The method of claim **14** wherein the step of coupling the groups to a switch comprises the step of coupling the groups to a switch comprising host facing ports, each host facing port coupled to a host, and a zoning table associating each virtual port ID to a host facing port.

17. The method of claim **16** wherein the step of using by the host a virtual port ID comprises communicating by the host only with groups having assigned virtual port IDs associated the host facing port to which the host is coupled.

18. The method of claim **17** wherein the storage array is a fibre channel array and wherein the at least one physical port is a fibre channel port.

19. A method comprising the steps of:

providing a storage array including a plurality of physical ports;

coupling the storage array to a switch via the physical ports;

arranging logical units in the storage array into a plurality of individual logical units of physical storage space organized into a plurality of groups of logical units of storage, each group having at least two of the individual logical units such that the at least two individual logical units are part of the group distinguished from being mapped to the group;

coupling the groups to a switch through at least one physical port on the storage array, each group being coupled to one or more physical ports of the plurality of physical ports on the array;

assigning to each group a unique virtual port ID that uniquely identifies the group for each physical port on the array to which it is coupled, with each group of the plurality of groups of logical units of storage that is coupled to two or more physical ports of the plurality of physical ports being assigned a unique virtual port ID for each of the two or more physical ports to which that same group is coupled such that multiple unique virtual port IDs are assigned to that same group, wherein a group of the plurality of groups of logical units of storage is assigned multiple virtual port IDs and two physical ports of the two or more physical ports, and wherein a first virtual port ID of the multiple port IDs corresponds to the first physical port of the two physical ports and a second virtual port ID of the multiple port IDs corresponds to the second physical port of the two physical ports;

coupling a host to the switch;

using by the host a virtual port ID to exchange data with the group in the storage array to which the virtual port ID is assigned.

20. The method of claim **19** wherein the step of assigning is performed by the switch.

21. The method of claim **20** wherein the step of coupling the groups to a switch comprises the step of coupling the groups to a switch comprising host facing ports, each host facing port coupled to a host, and a zoning table associating each virtual port ID to a host facing port.

22. The method of claim **21** wherein the step of using by the host a virtual port ID comprises communicating by the host only with groups having assigned virtual port IDs associated with the host facing port to which the host is coupled.

23. The method of claim **22** wherein the storage array is a Fibre Channel array and wherein the at least one physical port is a Fibre Channel port.

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